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In-plane linear polarization of luminescence and level anticrossings in GaAs/AlAs superlattices and quantum wells

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Abstract. In-plane linear polarization of luminescence under above-band-gap excitation was investigated in type II and type I GaAs/AlAs (001) quantum wells and superlattices together with the study of level anticrossing and ODMR. Correlation of such polarization with the preferential exciton localization was found and discussed in terms of coexistence of excitons and separately localized electrons and holes. The influence of the substrate temperature on the interface quality was revealed in type I GaAs/AlGaAs quantum wells from level-anticrossing spectroscopy.

Introduction

The use of luminescence to detect magnetic resonance and level anticrossing of excitons and carriers provided a new insight in the microstructure of quantum wells (QW) and superlattices (SL) (see [1–3] and references therein). In type II SL electrons and holes are spatially separated in the adjacent AlAs and GaAs layers, respectively. In LAC and ODMR experiments a direct link was established between the order of the exciton radiative levels and the interface, normal (AlAs on GaAs) or inverted (GaAs on AlAs), where it is localized. It was established that the lowest radiative exciton level is [110]-polarized for excitons localized at the normal interface and [$1\bar{1}0$]-polarized for excitons at the inverted interface [4]. Moreover, excitons localized at the opposite interfaces were found to have different exchange splittings due to asymmetry of the interface composition profiles [5]. This made possible separate investigations of the opposite interfaces with the use of ODMR and LAC spectroscopy. Anisotropic exciton localization was also revealed in type I GaAs/AlAs and GaAs/AlGaAs quantum wells from LAC in linearly polarized light [6].

In the present paper we report on a study of in-plane linear polarization of luminescence in GaAs/AlAs QW and SL under non-resonant excitation and its correlation with the preferential localization of excitons, electrons and holes. LAC spectroscopy was also used to analyze the interface quality in type I QW.

1 Results and discussion

GaAs/AlAs and GaAs/AlGaAs QW and SL were grown by MBE technique on (001) GaAs substrates kept at $T_s = 520{-}680°C$. A special type II SL (P233) with a gradient of GaAs/AlAs composition in the SL plane (from 6/6.5 to 8.5/8 monolayers) was grown with $T_s = 620°C$ with 30 s interruptions after GaAs layers. Actual composition of the samples was controlled by X-ray and Raman characterization. Photoluminescence was excited far above the band gap with an Ar-ion laser. LAC was recorded by monitoring linear or circular polarization of emission. 24 and 35 GHz ODMR spectra were obtained by monitoring microwave-induced variations of circularly polarized luminescence.

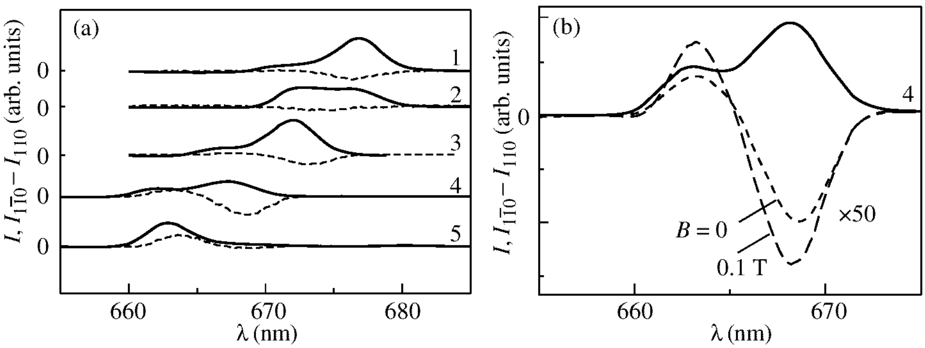

Fig. 1. (a) Emission spectra (full lines), and linear polarization of emission (dashed lines) in type II GaAs/AlAs SL P233 measured with different positions of excitation spot. (b) Linear polarization in zero magnetic field and at $B = 0.1$ T for one of the spectra shown in Fig. 1(a). $T = 1.6$ K

In all type II and type I structures we found linear polarization of the order of some per cent along [110] or [$1\bar{1}0$] directions in the SL plane. Fig. 1(a) shows luminescence spectra (full lines) and linear polarization signals (dashed lines) measured in different points of SL P233 (marked 1 to 5) which correspond to different GaAs/AlAs composition. Positive sign corresponds to polarization along [$1\bar{1}0$]. Linear polarization was found to depend on magnetic field ($B \parallel [001]$). This can be seen in Fig. 2(b) where spectral dependencies of polarization signal are plotted for zero field and $B = 0.1$ T, a value which is far enough from signals due to exciton level anticrossings.

Dependencies of the degree of polarization on magnetic field measured in the peaks of two emission lines (Fig. 1(a)) are shown in Fig. 2. Resonant LAC signals belong to excitons localized at the normal and inverted interface as marked in the picture. They have opposite signs since the order of radiative levels for two classes of excitons is inverted (see inset). The assignment of LAC was confirmed by ODMR measurements. From the values of hole g-factors and exciton exchange splitting it was concluded that emission in long-wavelength line appears from monolayer-high GaAs islands. LAC signals are superimposed on a broad line with the same shape as ODMR signal ascribed to electron–hole pairs. ODMR of electrons and holes is always observed in type II SL in addition to the exciton ODMR. A broad signal centered at $g_e \simeq 1.9$ is due to a distribution of zero-field splitting (exchange splittings) rather than a distribution of g-factors what was unambiguously confirmed by observation of multiquantum ODMR. The shape of this broad signal can be explained by a simple model of statistical distribution of interpair distances in the SL plane. This implies the existence of separately localized electrons and holes. Electrons are in AlAs layers and holes in GaAs layers which follows from the values of g-factors. Since an exchange-coupled e-h pair has the same energy level scheme as the exciton a distribution of exchange splittings averages LAC signals and gives rise to a broad line with the same shape as for ODMR. Dashed lines in Fig. 2 are result of calculations made for ODMR signal of e-h pairs.

As was shown before [6] analysis of LAC allows to obtain spectral dependencies of preferential exciton localization which depends on the interface microstructure. For a SL under consideration the ratio of exciton concentrations at the normal and inverted interfaces in the peaks of short- and long-wavelength emission lines are 1.6 and 0, respectively. Numerous measurements allowed to find a correlation between the sign and value of this

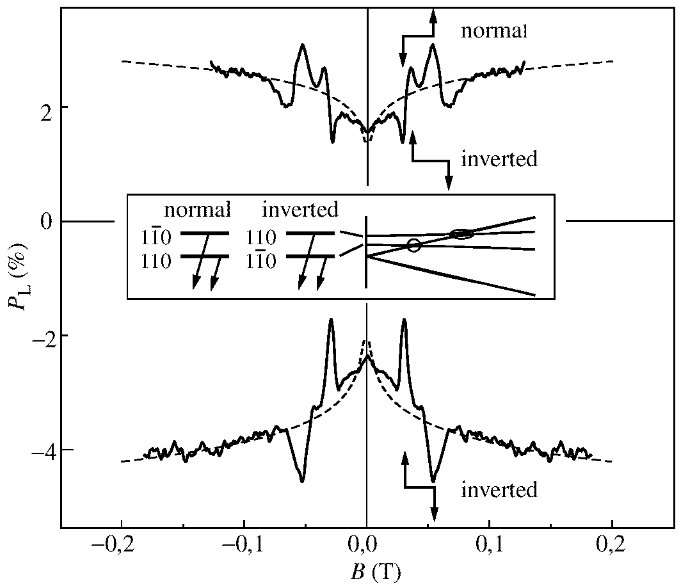

Fig. 2. Linear polarization of emission as a function of magnetic field measured in the peaks of short-wavelength (upper curve) and long-wavelength (lower curve) luminescence lines shown in Fig. 1(b). $B \parallel [001]$. $T = 1.6$ K.

polarization and relative concentrations of excitons at the opposite interfaces. Thus zero-field linear polarization can bring information on interface microroughness.

The zero-field polarization is obviously not connected with Boltzmann populations of the exciton radiative levels since its value increases with temperature. We tentatively ascribe it to distant pairs of separately localized electrons and holes. The existence of zero-field linear polarization is a manifestation of in-plane anisotropy in the distribution of the pair dipole moments.

In type I QW and SL in-plane anisotropy of the interfacial defects is responsible for anisotropic exciton localization and a splitting of exciton radiative levels. Linear polarization of emission and LAC recorded by monitoring circular and linear polarization of emission in two QW structures both containing 25 Å and 50 Å QW but grown by MBE at different substrate temperatures are shown in Fig. 3. Linear polarization along [1$\bar{1}$0] is observed, i.e. in the direction of a preferential orientation of interface defects. Increasing substrate temperature improves interfaces which is manifested in the narrowing of exciton LAC (see inset in Fig. 3(a)) and an increase of zero-field linear polarization (Fig. 1(a)). Increasing disorder of the interface in the samples grown at lower temperature is illustrated by comparison of LAC signals. It is possible that separately localized e-h pairs which were recently found in type I structures [7] contribute to zero-field linear polarization.

In conclusion, correlation of in-plane zero-field linear polarization of luminescence with the preferential exciton localization was found in type II and type I GaAs/AlAs QW and SL and discussed in terms of coexistence of excitons and separately localized electrons and holes. The influence of the substrate temperature on the interface quality was revealed in type I GaAs/AlGaAs quantum wells from level-anticrossing spectroscopy.

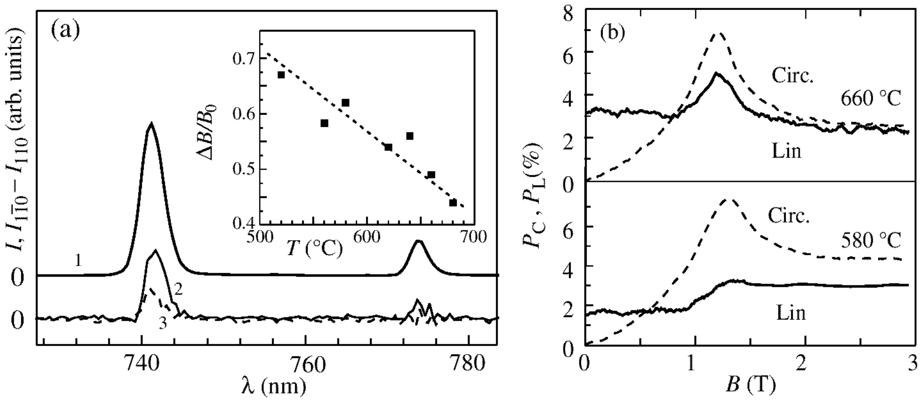

Fig. 3. (a) Emission spectra (1) and linear polarization (2,3) in two type I GaAs/AlGaAs QW samples MBE-grown at 660 °C (curves 1, 2) and 560 °C (1, 3). Inset shows a dependence of a linewidth of LAC signals recorded via circular polarization in 25 Å QW on temperature of substrate during the MBE growth. (b) Linear and circular polarization of emission in 25 Å QW for these two QW-structures. $T = 1.6$ K.

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